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OPTICAL BEHAVIOUR OF YTTRIUM DOPED NICKEL-MAGNESIUM-CADMIUM FERRITE PREPARED BY SOL-GEL AUTOCOMBUSTION METHOD

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ABSTRACT

The present work represents, the Yttrium doped $Ni_{0.4}$ $Mg_{0.4}$ $Cd_{0.2}$ Fe_{2-y} O_4 Nanoferrites (where y = 0.025 to 0.125) synthesized using sol-gel autocombustion method. The structural and optical properties were studied using XRD, FTIR and UV-Visible spectroscopy for the prepared samples. The XRD pattern shows that the structure of prepared nanoparticles is spinel with average grain size lies in the range between 17 to 25 nm. Lattice parameter was found to increases with Zn concentration and this may be due to the larger ionic radius of the Y^{3+} ion. FTIR spectroscopy confirmed the formation of spinel ferrite and showed the characteristics absorption bands around 554, 1058, 1384, 1600, 2919, 3434 and 3855 cm^{-1}. The energy band gap was calculated for samples with different ratio and average band gap energy was found to be 4.0743 eV. The substitution was resulted in slight increased in the lattice constant and that sequentially may lead to the slightly increased in the energy gap. Also found that it is in the range of semiconductor materials.

KEYWORDS: Sol-Gel Autocombustion Method, Ferrite Nanoparticles, Optical Properties and XRD

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Original Article

INTRODUCTION

Nanotechnology is the combination of the branches of science such as engineering, physics, chemical engineering, medical biology and the applications of nanomaterials[1]; which are applicable in electromechanical devices, optical devices, magnetic devices, and tissue engineering[2]. The attractive, qualitative, intelligent functional materials, components and systems are designed by new material nanotechnology technique[3-4]. Superior physical properties of ferrites like recording are used for magnetic resonance imaging enhancement, catalysis, and sensors[5]. The MFe_2O_4 is the chemical formula of spinel ferrites where M is divalent metal cations[6]. Magnesium ferrite ($MgFe_2O_4$) has an inverse spinel structure in which Mg^{2+} cations are on octahedral sites and zinc ferrite ($ZnFe_2O_4$) has normal spinel structure in which Zn^{2+} cations occupy tetrahedral sites[7-10]. The intensive properties of the small scale size spinel ferrites were used for biomedical applications[11-13]. The co-precipitation, hydrothermal, sol-gel, etc techniques were used to produce high quality nanoparticle and particle size in the range between 2 to 100 nm[14-15].

In this work, $Ni_{0.4}$ $Mg_{0.4}$ $Cd_{0.2}$ Y_y Fe_{2-y} O_4 Nanoferrites (where y = 0.025 to 0.125) were synthesized using co-precipitation methods. X-ray diffraction (XRD) was used in order to investigate the structural of Y^{3+} substituted nickel-magnesium-cadmium nano-ferrites and to determine the lattice parameters and the space group symmetry. Ultraviolet visible spectrometer (UV-Vis) and Fourier Transform Infrared Spectroscopy (FTIR) were used to

investigate the optical properties of crystallite nanoparticles.

MATERIAL AND METHOD

The Y^{3+} doped in Ni-Mg-Cd ferrite powders were synthesized by sol-gel autocombustion method at low temperatures for different compositions of $Ni_{0.4}\,Mg_{0.4}\,Cd_{0.2}\,Y_y\,Fe_{2-y}\,O_4$ (where y = 0.025, 0.050, 0.075, 0.100 and 0.125). According to respective molar amounts of yttrium nitrate, magnesium nitrate, nickel nitrate, cadmium nitrate, ferric nitrate of AR grade with 99% purity and citric acid as a fuel were used with stoichiometric ratio (1:3) proportion to obtain the final product[16]. All these chemicals were dissolved in double distilled water and stirred till to obtain the homogeneous solution. Ammonium hydroxide was added drop by drop to maintain pH between 7 to 8 during the stirring process and solution was continuously stirred with 80-100 $^{\circ}C$ for about 4-5 hours to obtain sol. After 4-5 hours, gel converts into ash and ash convert into powder. Finally get fine powder of $Ni_{0.4}\,Mg_{0.4}\,Cd_{0.2}\,Y_y\,Fe_{2-y}\,O_4$ ferrite nanoparticles after auto combustion. The powder was sintered at 400 $^{\circ}C$ for 2 hours.

The X-ray diffractometer (Cu-Kα radiation of wavelength 1.54 A^0 at 40 kV) were performed a scanning 20 to 80 degree with step of 0.02 degree per second for each prepared sample to study structural characterization and used to determine lattice parameter with grain size. The optical characteristics was studied using Fourier Transformation Infrared spectroscopy (FT-IR) of Bruker 3000 Hyperion microscope with vertex 80 single point detector performing images resolution ranging between 7500 to 450 cm^{-1} and UV-Visible spectroscopy. Further investigations of the optical properties are under way to elucidate the effective role of inter particle interactions in these samples.

The general chemical reaction of the synthesis sample is as follows;

$$\begin{aligned} &Ni(NO_3)6H_2O + Mg(NO_3)6H_2O \\ &+ Cd(NO_3)_2.6H_2O + Y(NO_3)_2.9H_2O \xrightarrow{80\,^0C \text{ for } 4\text{-}5 \text{ hrs}} NiMgCdYFe_2O_4 \\ &+ Fe(NO_3)_3.9H_2O + 3C_6H_8O_7 \end{aligned}$$

3. RESULTS AND DISCUSSIONS

3.1 Structural Studies

XRD Analysis: The prepared powders of Y^{3+} doped Ni-Mg-Cd nanoferrite were characterized by X-ray diffraction and pattern of sintered powder is shown in figure-1. The XRD pattern conform the formation of a homogeneous spinal cubic structure and the broad peaks indicates fine particle nature of the nanoparticles. Scherer's formula was used to determine the particle (grain) size.

$$t = \frac{0.9\,\lambda}{\beta\, Cos\,\theta} \qquad (1)$$

Where, 'λ' is wavelength of x-ray,

'θ' is peak position, and

'β' is FWHM of the peak position.

The average particle (grain) size of nanoparticles was noted in table-1 and it is ranging between 17 to 25 nm. This indicates if the concentration of Y^{3+} doped increases then average particle size decreases. Lattice parameters were

calculated for sintered sample is ranging from 1.9228 to 2.1300 A^0. The value of lattice constant of Ni-Mg-Cd ferrite shows the expansion of unit cell with rare earth yttrium doping when compared with pure yttrium ferrite and the deviation in lattice parameter attributed to the cations rearrangement in the nanosize prepared ferrites. The Y^{3+} substituted ferrites have high stability relative to Ni-Mg-Cd ferrite due to doping of large ionic radius of Y^{3+} ions (0.9 A^0) with small ionic radius Fe^{3+} ions (0.645 A^0).

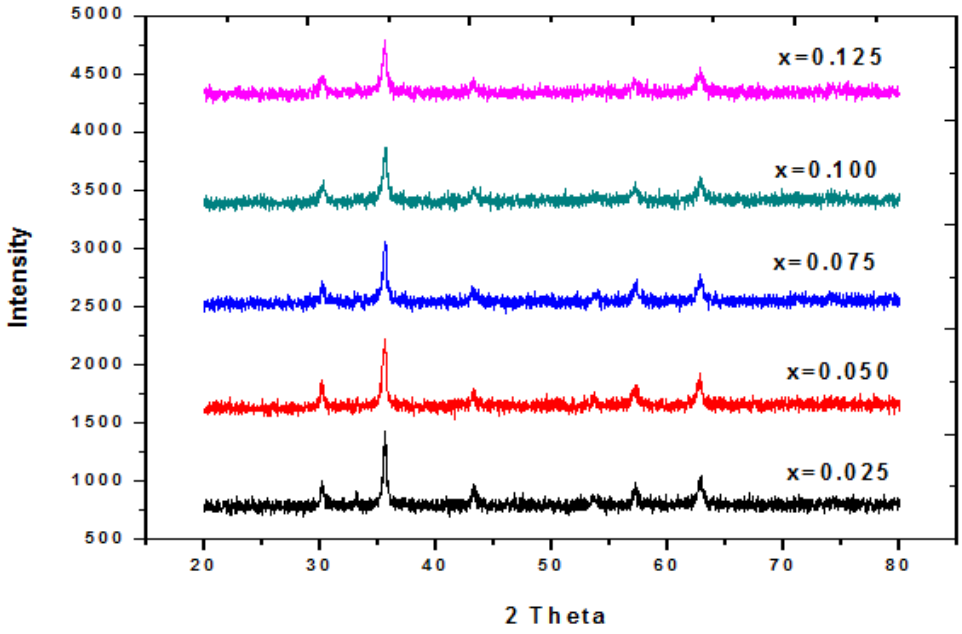

Figure 1: X-ray Diffraction Pattern of $Ni_{0.4}Mg_{0.4}Cd_{0.2}Y_yFe_{2-y}O_4$

Table 1: The Grain Size of Prepared Samples $Ni_{0.4}Mg_{0.4}Cd_{0.2}Y_yFe_{2-y}O_4$ by x-Ray Diffraction

Obs. No.	Composition	Grain size (t) nm	Lattice constant (a) A^o
1	y = 0.025	23	2.1309
2	y = 0.050	25	2.1338
3	y = 0.075	21	2.1305
4	y = 0.100	22	2.1300
5	y = 0.125	17	1.9228

Optical Studies

FTIR Analysis: In order to investigate the chemical functional groups on the synthesized $Ni_{0.4}Mg_{0.4}Cd_{0.2}Y_yFe_{2-y}O_4$, FTIR spectroscopy are performed. The FTIR spectra of the prepared $Ni_{0.4}Mg_{0.4}Cd_{0.2}Y_{0.100}Fe_{1.900}O_4$ are shown in figure 2 to know the bonding characteristics of the materials. The peaks at 429.68 cm^{-1} and 554.13 cm^{-1} are the peaks of Fe-O bond in Y doped Ni-Mg-Cd ferrite and it is arises due to the lattice vibrations of the oxide ions against cations. The peak at 1384.13 cm^{-1} indicates the presence of O-H bond due to bending vibration. The broad peak at 3434.50 cm^{-1} gives presence of hydroxyl group in the material and indicates that the material absorbed moisture from atmosphere during analysis.

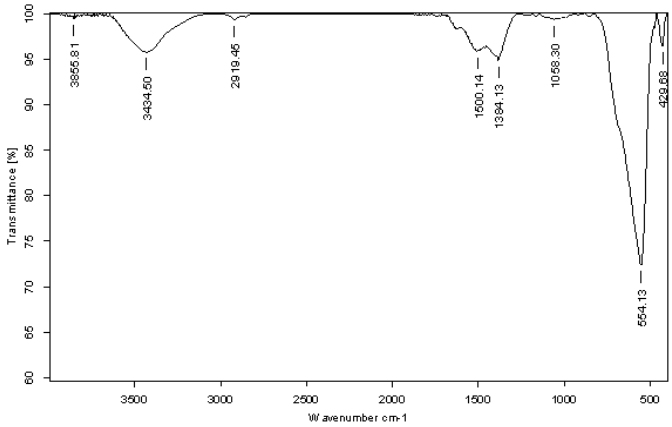

Figure 2(a): FT-IR Spectrum of $Ni_{0.4}Mg_{0.4}Cd_{0.2}Y_{0.100}Fe_{1.900}O_4$

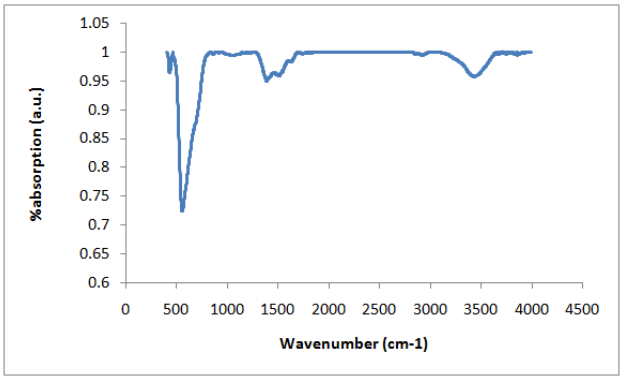

Figure 2(b): Absorption Spectra of $Ni_{0.4}Mg_{0.4}Cd_{0.2}Y_{0.100}Fe_{1.900}O_4$

The intense absorption bond is observed at 554.13 cm^{-1} which shows the characteristic bond of spinel structure which may due to presence of Fe-O and Y-O bonds or crystalline nature of Y doped Ni-Mg-Cd ferrite. Hence, FT-IR analysis supports the observation of XRD analysis and confirms the crystalline nature of ferrite. So, the peaks at 476 cm^{-1} and 1058 cm^{-1} confirms the presence of yttrium doped in Ni-Mg-Cd ferrite. Finally, the doping of Y^{3+} on Ni-Mg-Cd ferrite was confirmed by different pattern of the plots and the difference in relative position and intensity of the peaks appeared in the FT-IR plots of the prepared samples. This indicates normal ferromagnetic materials.

UV-Visible Analysis: The figure-3 shows optical properties were studied from UV-Visible spectroscopy to calculate the band gap energy. In the absorption molecules of non-bonding electrons can absorb the energy in the form of ultraviolet or visible light to excite this electron to higher or anti-bonding molecular orbit. The energy band gap was calculated for samples with different ratio using following formula;

$$E = \frac{h\,C}{\lambda} \tag{2}$$

Energy band gap was found to be 3.9935, 4.0390, 4.0655, 4.1196 and 4.1541 eV. The substitution was resulted in slight increase in the lattice constant and that sequentially may lead to the slightly decrease in the energy gap. The average Band gap of prepared sample is 4.0743 eV and wavelength absorb by 508 nm. It is in the range of semiconductor materials.

Table 2: The Band Gap Energy of $Ni_{0.4}Mg_{0.4}Cd_{0.2}Y_yFe_{2-y}O_4$ by UV-Visible Spectroscopy

Obs. No.	Composition	Wavelength (nm)	Band gap energy (eV)
1	**y=0.025**	**310.5**	3.9935
2	**y=0.050**	**307.0**	4.0390
3	**y=0.075**	**305.0**	4.0655
4	**y=0.100**	**301.0**	4.1196
5	**y=0.125**	**298.5**	4.1541

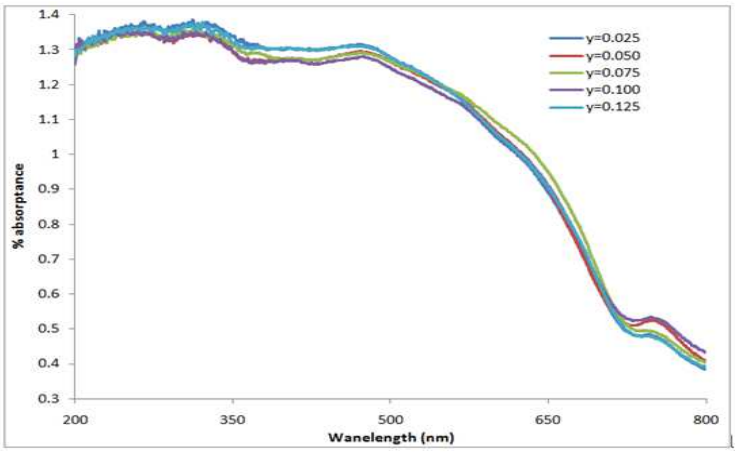

Figure 3: UV-Visible Spectra of $Ni_{0.4}Mg_{0.4}Cd_{0.2}Y_yFe_{2-y}O_4$

CONCLUSIONS

The $Ni_{0.4}$ $Mg_{0.4}$ $Cd_{0.2}$ Y_y Fe_{2-y} O_4 nanoferrites were synthesized using sol-gel autocombustion technique. The increase in the Y^{3+} concentration gives the significant changes in the particle size and optical properties of the composition $Ni_{0.4}Mg_{0.4}Cd_{0.2}Y_yFe_{2-y}O_4$ (where y = 0.025, 0.050, 0.075, 0.100 and 0.125). The FT-IR spectroscopy study shows two main metal oxygen bands in the range of 429.68 to 554.13 cm^{-1} confirms the formation of cubic spinel phase structure of Y^{3+} substitute in Ni-Mg-Cd ferrite. The synthesis of nanoparticles with crystalline size decreases and lattice constant increases as the concentration increases and is in the range of 17 to 25 nm for 400 ^oC. The UV-Visible analysis shows band gap energy increases with increase in Y^{3+} concentration. The UV-Visible study shows average Band gap energy is 4.0743 eV and wavelength absorb by 508 nm. This result prepared ferrite materials is in the range of semiconductor materials.

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